MSFC Solar Instrumentation Group



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With contributions from Sabrina Savage

The University of Alabama in Huntsville
&
NASA Marshall Space Flight Center

The Great American Solar Eclipse

August 21, 2017

National Aeronautics and Space Administration

NASA

What is a Solar Eclipse?

A **solar eclipse** happens when the Moon, as it orbits Earth, fully or partially blocks the light of the Sun, thus casting its shadow on Earth.

Observers within the path of totality can expect to see something like the image below. bservers outside the path of totality will see the Sun partially eclipsed as a crescent Sun (with safe filters).

Greatest Eclipse

Time	Location
10:17 a.m. PDT	Lincoln Beach, OR Depoe Bay, OR
11:26 a.m. MDT	Lime, ID
1:19 p.m. CDT	Valley View, MO Bloomsdale, MO
1:28 p.m. CDT	Calistia, TN
2:47 p.m. EDT	Bethera, SC

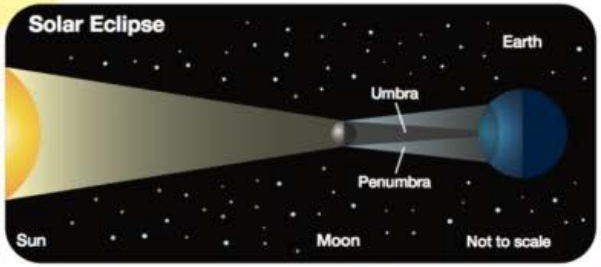


©1999 by F. Espenak, MrEclipse.com

After the 2017 solar eclipse, the next **total solar eclipse** visible over the continental United States will be on **April 8, 2024**.



©1999 by F. Espenak, MrEclipse.com



If the Sun is scaled to about 10 cm (3.9 in), Earth would be about 10 meters away (33 feet).

The predicted path of the August 21, 2017 solar eclipse

Duration of Greatest Eclipse:
2 min 40 sec
(18:25 UT=13:25 CDT or 1:25 p.m. CDT)

Location Greatest Eclipse:
36 deg 58 min N; 87 deg 40 min W
(between Princeton and Hopkinsville, KY)

Path Width: **approximately 115 km**

Eclipse Predictions by Fred Espenak, GSFC, NASA-emeritus





http://mail.colonial.net/~hkaiter/index.html

The NASA image above shows the Moon's umbral shadow as seen from the International Space Station during the total solar eclipse on 29 March 2006.

Never look directly at the Sun unless you have filters that you know are safe.

For more information: http://eclipse/gsfc.nasa.gov/SEhelp/safety.html

For more information about solar eclipses: http://eclipse.gsfc.nasa.gov/solar.html
http://eclipsewise.com/solar
http://eclipse2017.org/

www.nasa.gov

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FL–2015–07–60–MSFC G–157953

Why study the Sun?

- The Sun is our nearest star: it is a class G2V main-sequence star.
- The Sun is the single greatest influence on the Earth and all of its species.
- Understanding the interaction between the Sun and Earth is imperative knowledge for civilization as we know it.
- The physics that occurs within the Sun and solar atmosphere is the origin of the Earth – Sun relationship

Earth – Sun relationship

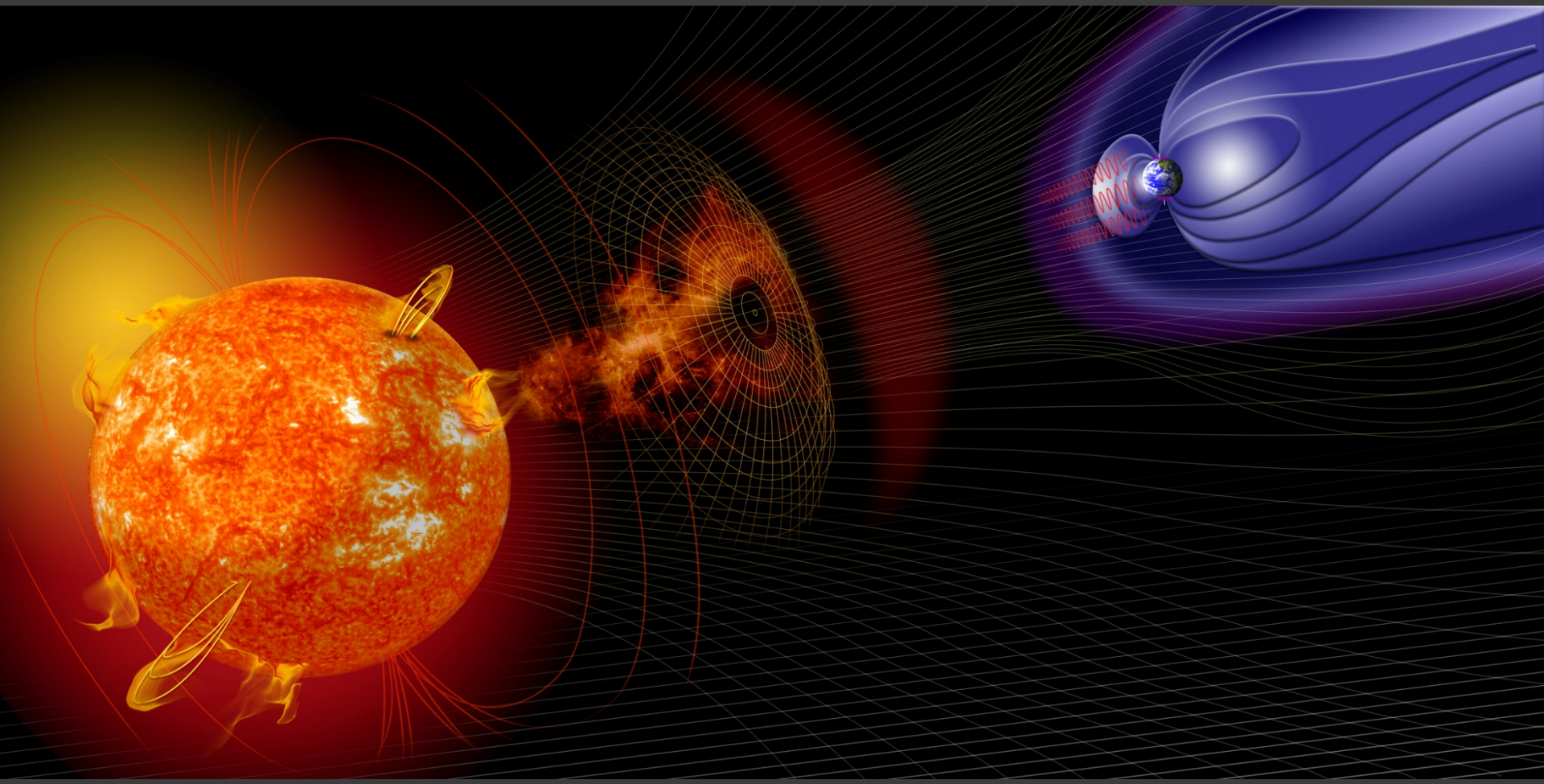


Image credit : NASA – https://www.nasa.gov/sites/default/files/525022main_faq12_0.jpg

What is the Sun made of?

- Like all stars, the Sun is a giant ball of plasma
  - Plasma is an ionized state of mater, where electrons flow with little – to – none resistance, generating electric and magnetic fields

- The Suns energy originates at the core – it is the product of nuclear fusion H and He into heavier elements.
  - Photons generated at the core of the Sun travel from the core, to the surface – this process is estimated to take 10s, or even 100s of thousands of years.

The Sun is a HOT ball of gas, with an entangled mess of electric and magnetic fields!

A beautiful mess!

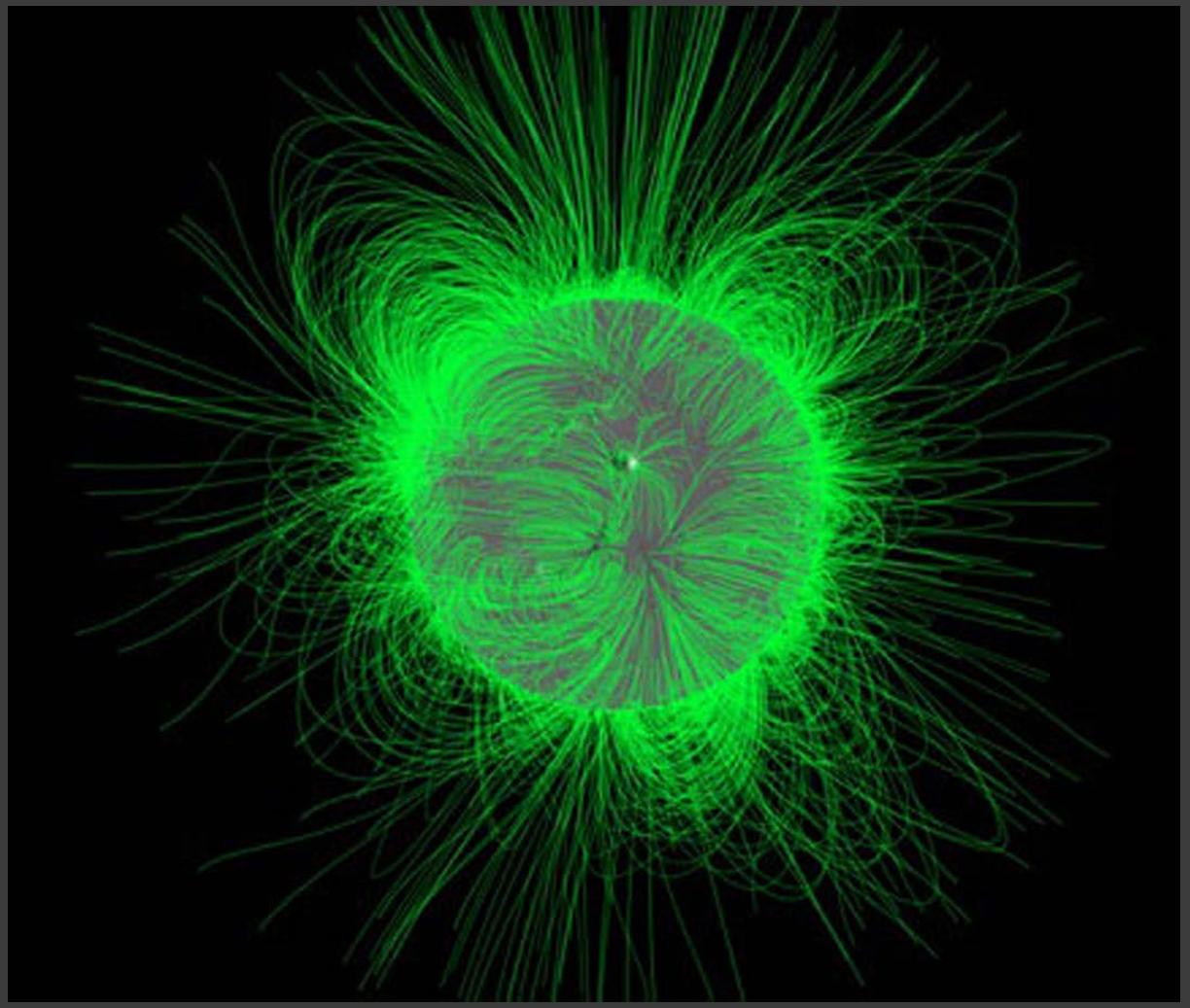


Image credit: NASA – https://www.nasa.gov/sites/default/files/thumbnails/image/faq2.jpg

The Sun has layers…

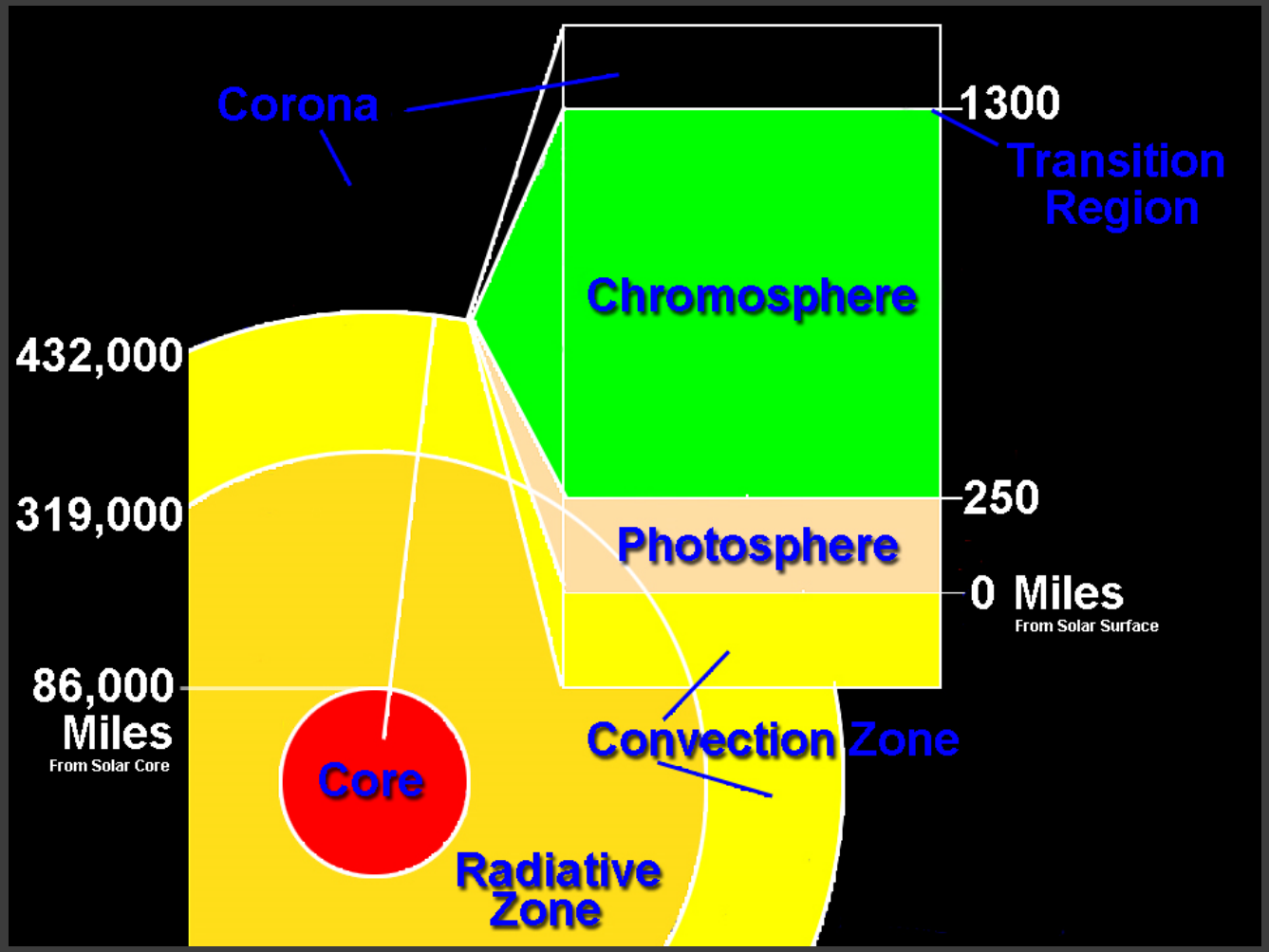
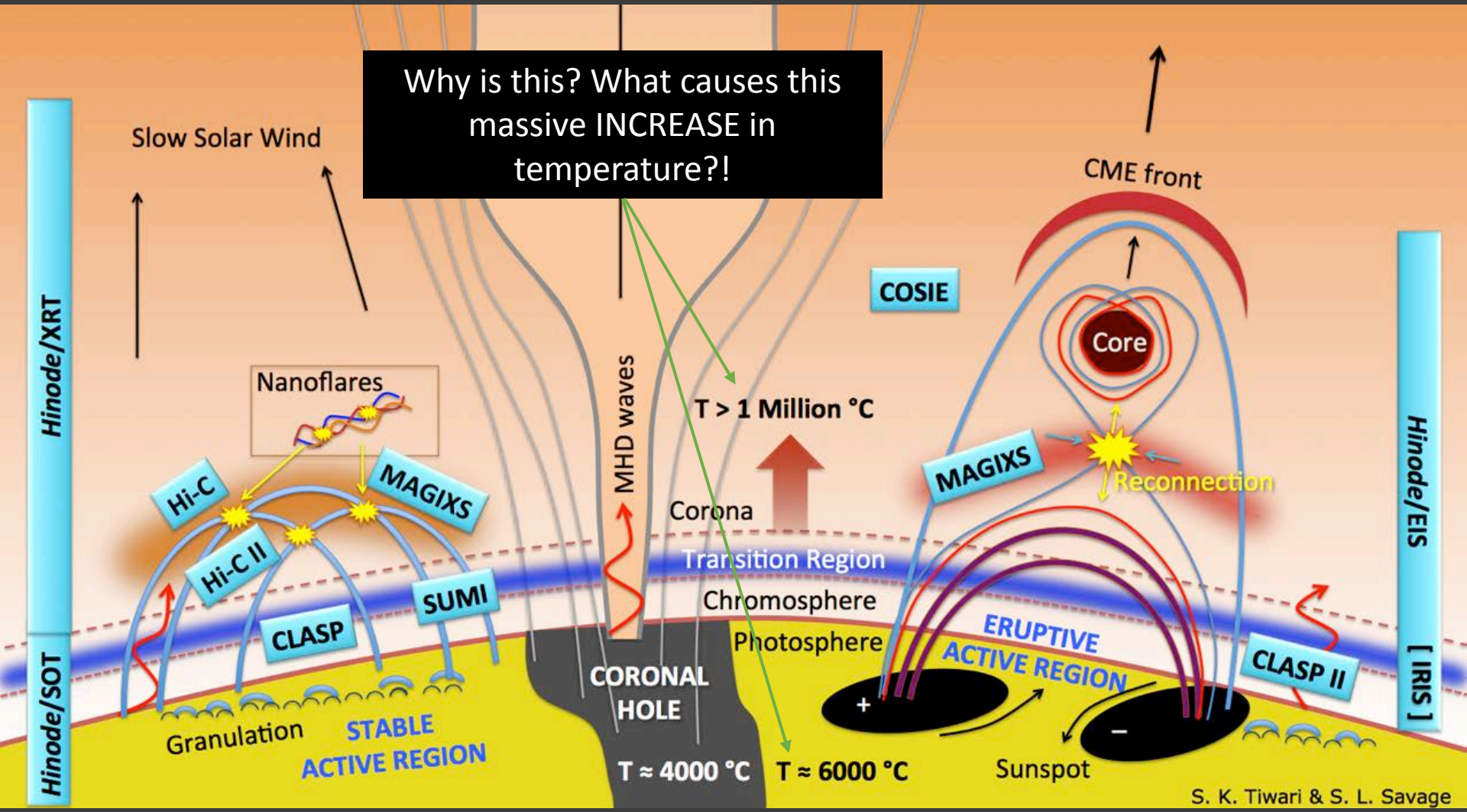


Image credit: NASA – https://www.nasa.gov/mission_pages/iris/multimedia/layerzoo.html

Another look at the Sun



Active region loops

- At the photosphere, plasma and magnetic fields bubble and emerge – think of boiling water
- In some cases, active regions emerge
  - These are areas of intense magnetic fields that contain networks of plasma filled filed lines called loops
- These loops extend out of the photosphere and into the chromosphere, and sometimes the corona.
  - In doing so, loops can become twisted, knotted, and intertwined with each other

Active region loops

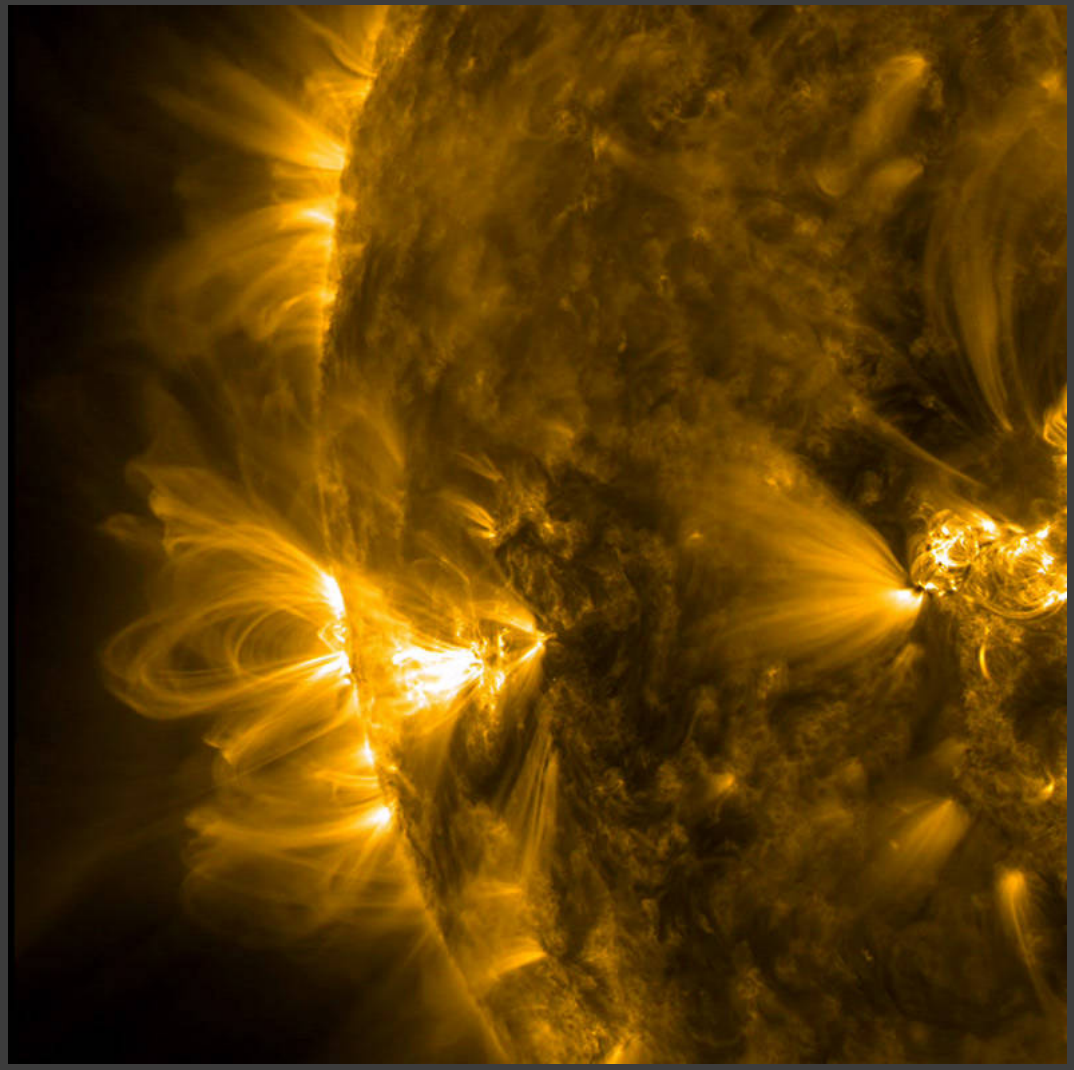


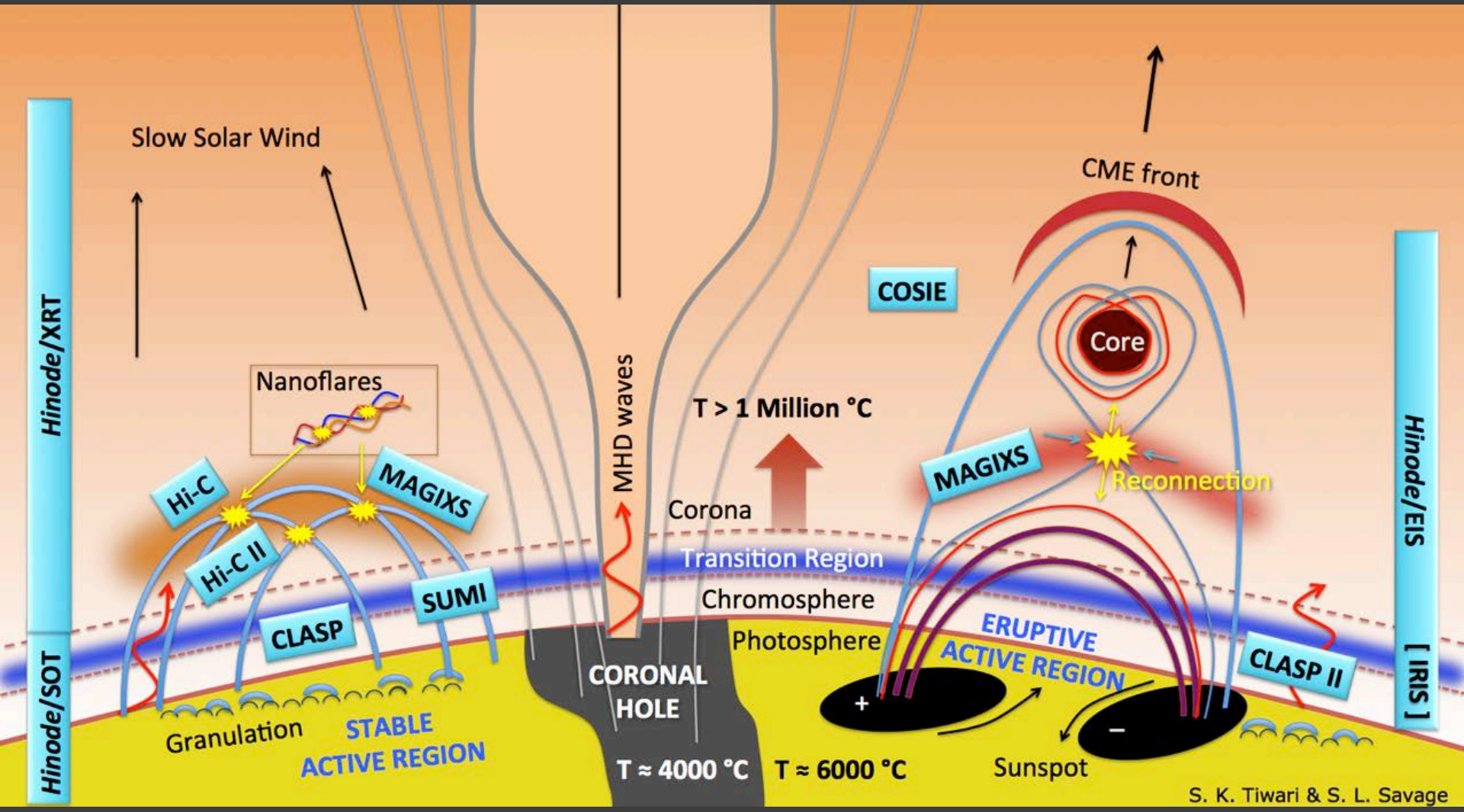
Image credit: NASA/Solar Dynamics Observatory
https://www.nasa.gov/content/coronal-loops-in-an-active-region-of-the-sun

What “physics” are we interested in understanding?

- Eventually loops can end up in a highly stressed state
- When they do, loops catastrophically break – field lines reform with other adjacent field lines, ending up in a reorganized, stable state
- The potential energy stored in these loops is instantaneously released during this process…
  - We hypothesize that this type of mechanism is the main cause of plasma heating

<u>This is the physics we want to understand!</u>

How we think of the Sun



Our team's focus

- One of the most interesting phenomena in solar physics is the heating of the sun's corona.
  - Temperature varies from 6000K on the photosphere to 1MK in the corona
  - It is still very much a mystery as to why this occurs
  - Leading hypothesis suggest many small scale events contribute to this phenomena
- We study this phenomena not only to explain these observations, but to broaden our knowledge of the fundamental physics of plasma dynamics
  - Thermal and radiative heat transfer
  - Influence of strong magnetic fields on hot, low-density plasma
  - Magnetic reconnection
  - Wave dissipation

Progress in the community?

- There are several, well studied theoretical hypothesis about coronal heating – magnetic reconnection is our “favorite”

- But observationally, we community is limited…the picture is incomplete

The complete picture

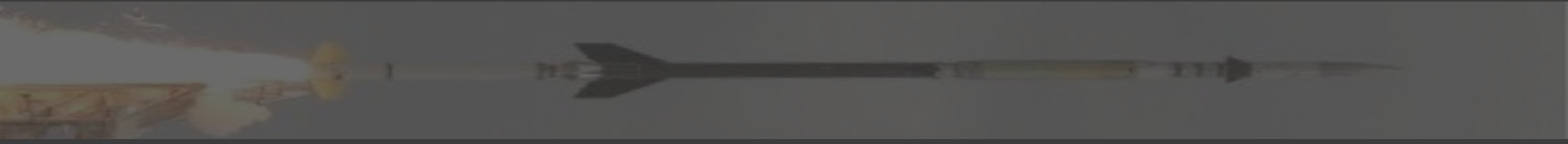
- Since the atmosphere of the Sun has different characteristic temperatures, each layer emits a different band of wavelengths
  - The hotter the temperature, the shorter the wavelength
- Our studies required detailed, high-resolution observations at most of these wavelengths

What is missing?

- We do not have complete spectral coverage at high (1 MK – 7 MK) temperatures (X-ray band)

- Moreover, there are limited instruments with ultra-high resolution to observe the solar atmosphere at fine scales (~100 km in length)

<u>This is the scientific motivation behind our instruments!</u>



Sound Rocket Instruments at MSFC

Sounding Rocket Instruments at MSFC

Hi-C I (J. Cirtain, PI)
Flew from WSMR on July 11, 2012
Hi-C II (J. Cirtain, PI)
Flew from WSMR on July 25, 2016 – In-flight anomaly
Hi-C II' (A. Winebarger, PI)
Proposed launch Spring, 2018

CLASP I (A. Winebarger, PI)
Launched from WSMR on September 3, 2015
CLASP II (D. McKenzie, PI)
Proposed launch Spring, 2019

MaGIXS (A. Winebarger, PI)
Proposed launch Summer, 2018-19

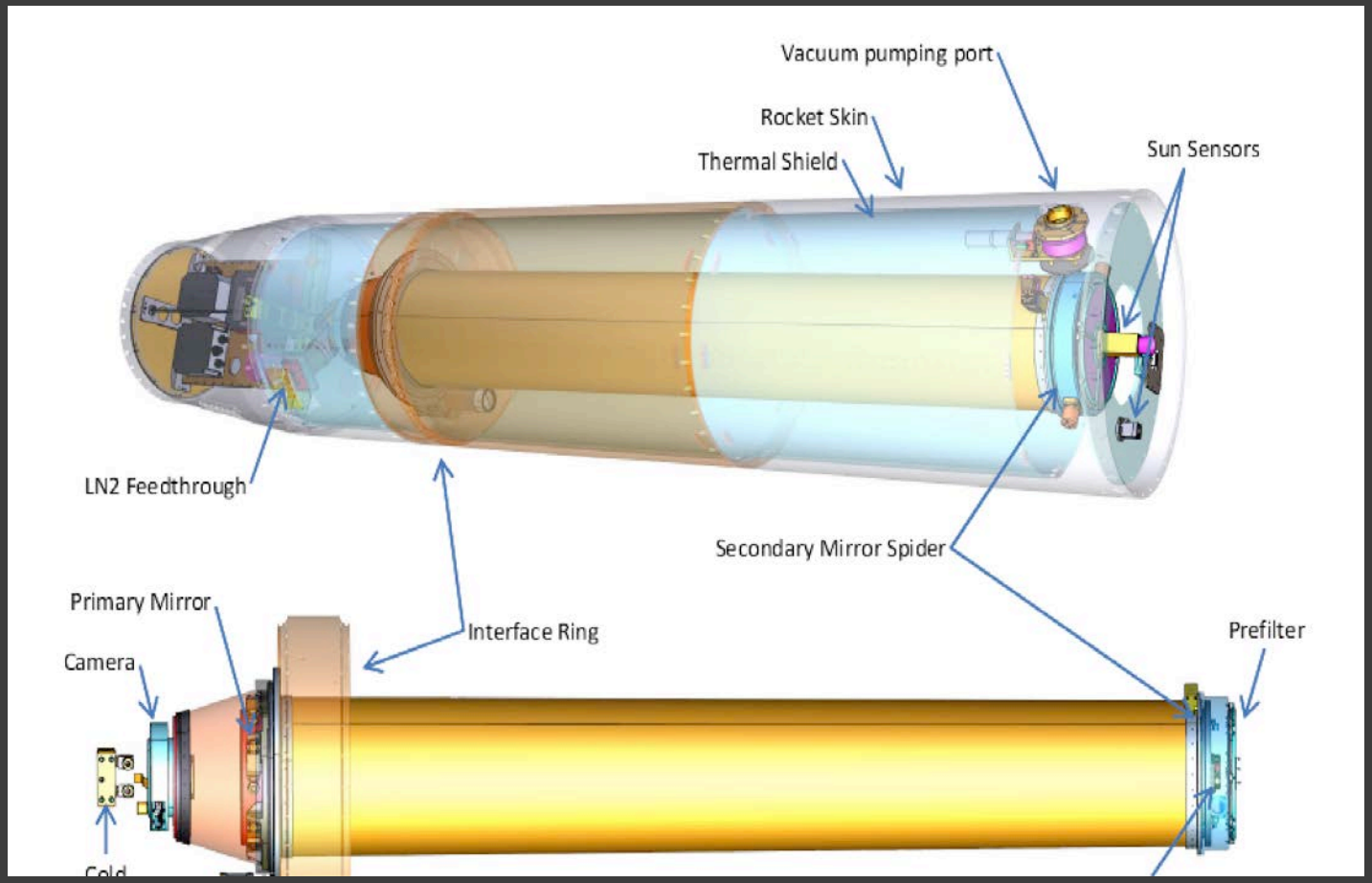
ESIS (A. Winebarger, Co-I & K. Kobayashi, Co-I)
Proposed launch Summer, 2018

FLOWN
FUNDED
PROPOSED

High-resolution Coronal Imager (Hi-C)

Telescope design capable of ~150 km (~93 miles) spatial resolution!

Pointing stability necessary to achieve resolution goal.



Hi-C



Hi-C Launch
White Sands, NM
July 11, 2012



Hi-C recovery team



Hi-C rocket with parachute

Hi-C

Active Region 11520
July 11, 2012

24 publications for 5 minutes of data!

Science highlights:

- Braided loops triggering energy release through magnetic reconnection (*Cirtain et al. 2013, Nature*)
- Subflare triggers
- Nanoflare heating
- Loop sub-structure
- Moss dynamics
- Penumbral jets
- Flows along filament threads
- MHD waves

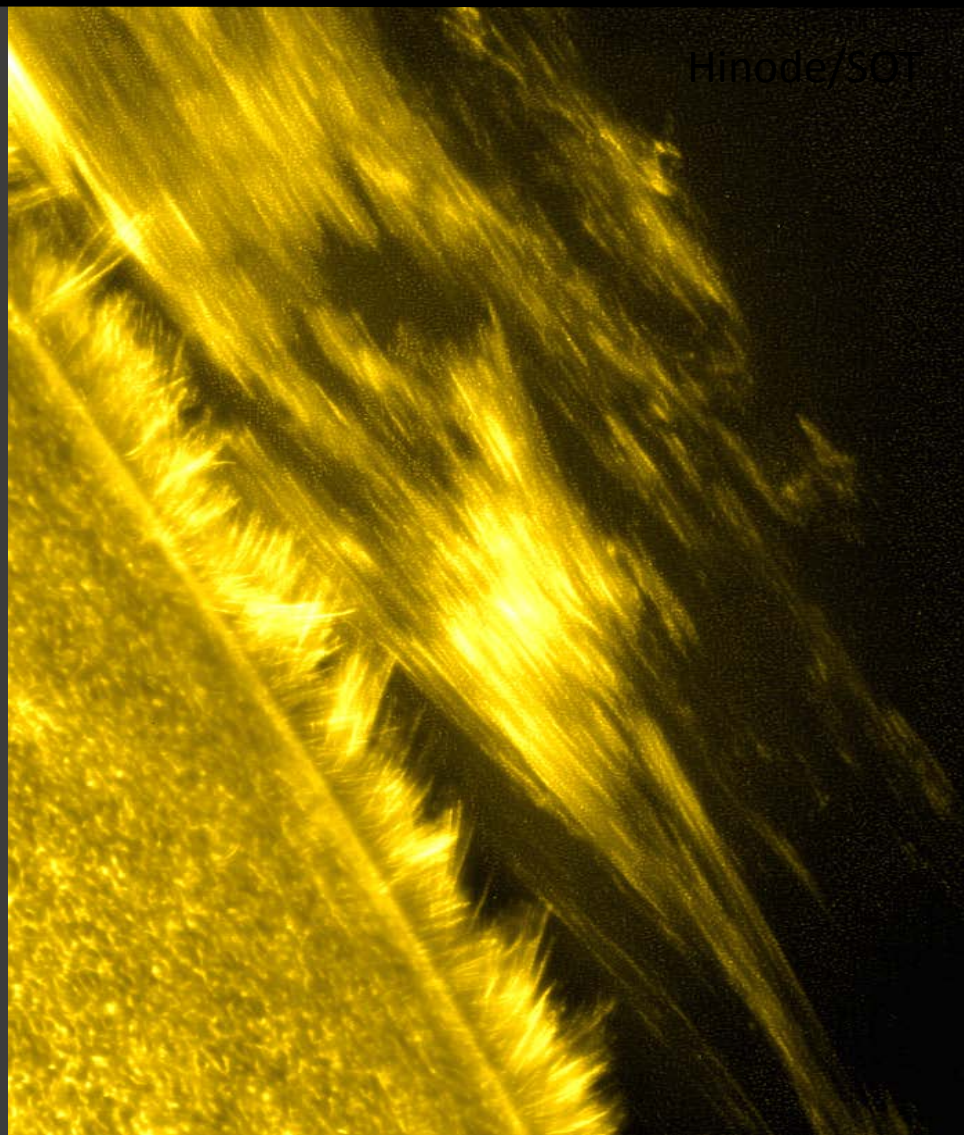
Hi-C II

Hi-C II(‘) will explore the important Chromospheric-Coronal Connection by targeting specific candidates likely to contribute to coronal heating:

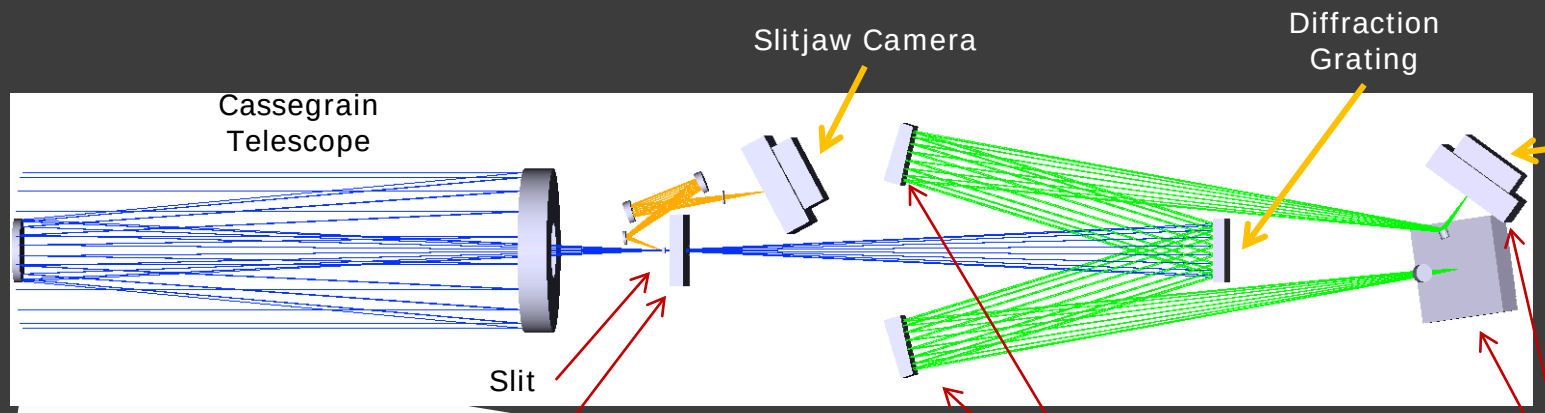
1. Type II spicules
2. Hot active region core loops

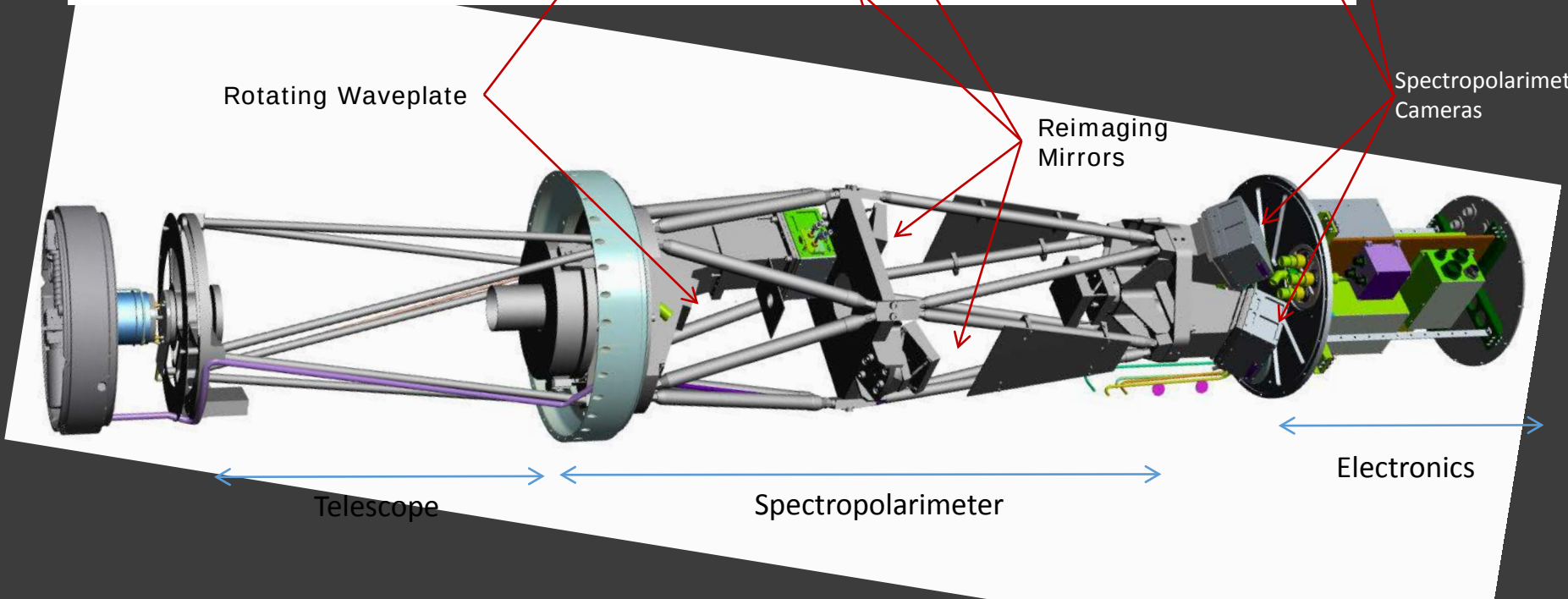
Updates for re-flight:

- Cooler bandpass centered on 173 Angstroms
- Significant improvement in camera quality (cameras for this instrument being developed concurrently for other instrumentation where low noise is critical)



Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)



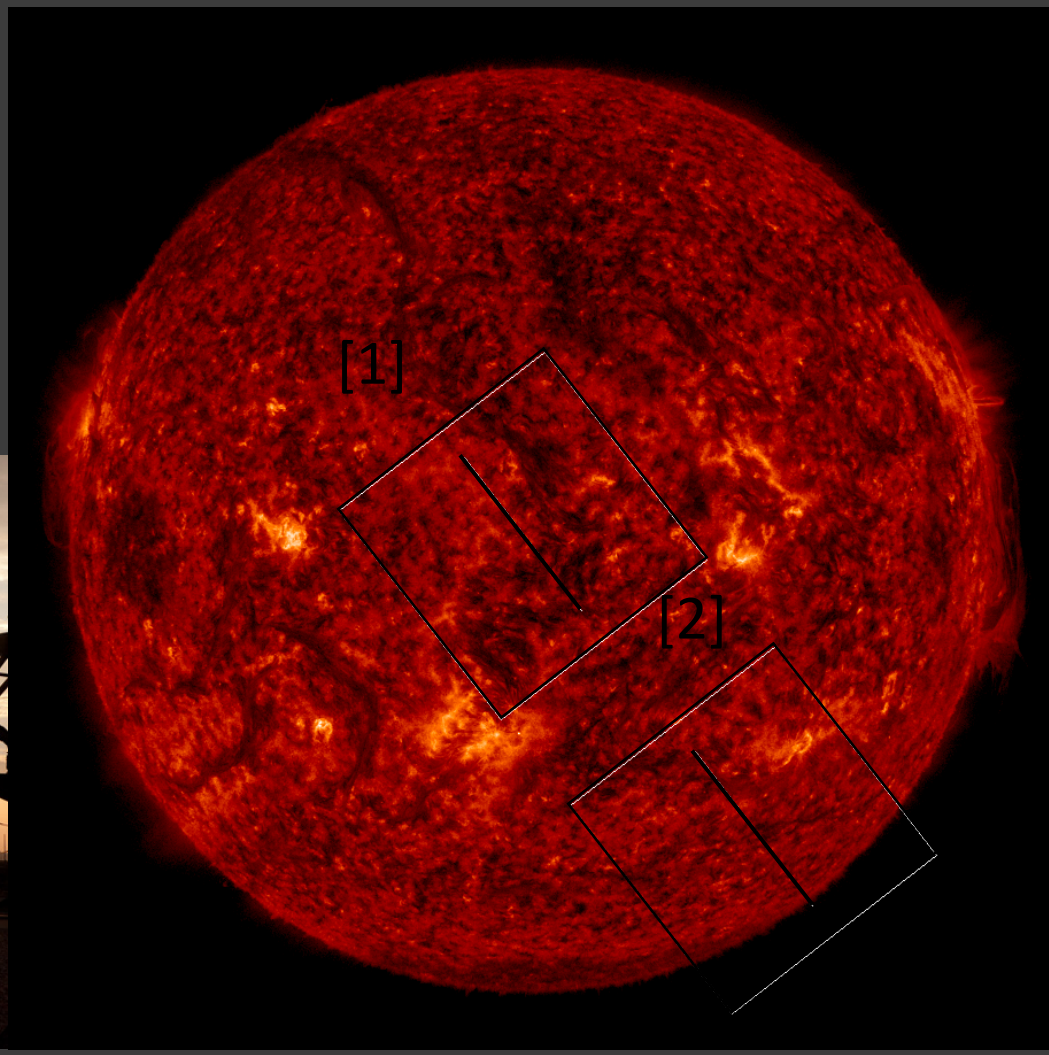


Objective: Use the polarization to infer the chromospheric thermal structure and magnetic field.

- Requires accurate calibration
- Requires advanced theoretical modeling for interpretation

Launched September 3, 2015





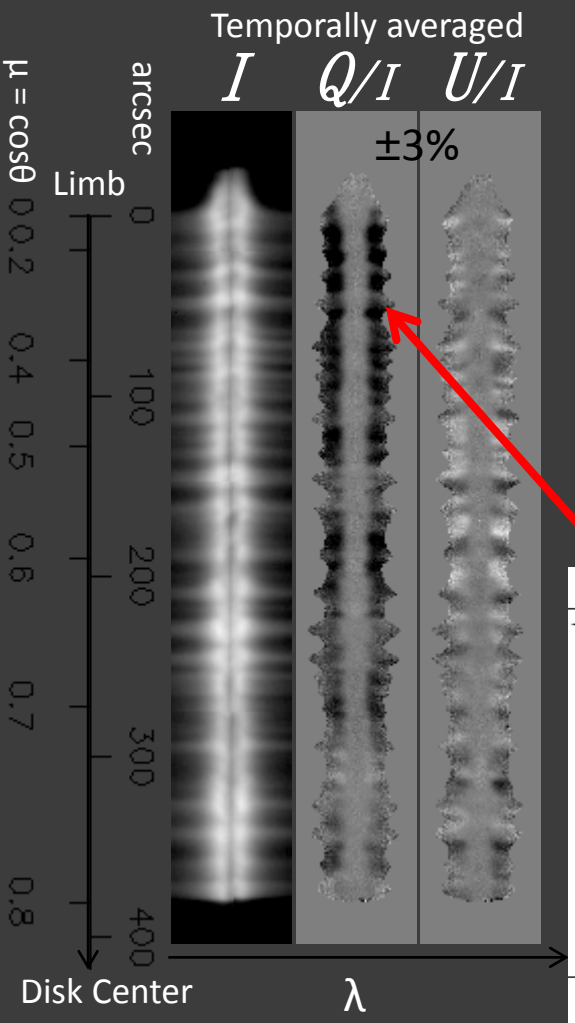

CLASP
Chromospheric Lyman-Alpha SpectroPolarimeter

CLASP

Chromospheric Lyman-Alpha SpectroPolarimeter

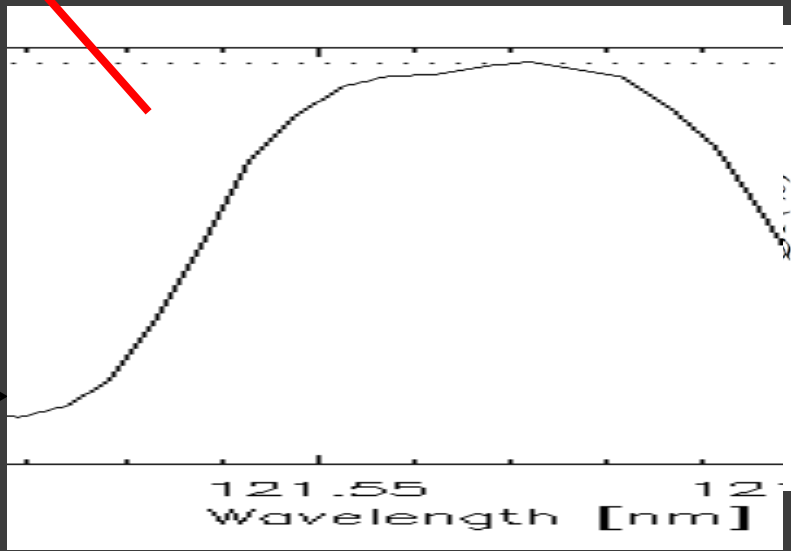


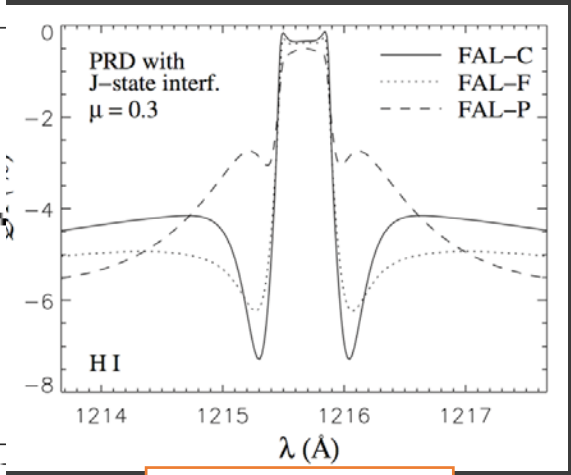
CLASP
Chromospheric Lyman-Alpha SpectroPolarimeter



Further calibrations/investigations are required, but the initial results are…

- **A few %** of polarization in the wing, and **a few of 0.1 %** in the core.
- A clear **C-to-L variation** in the wing of Q/I.
- Small-scale structures along the slit.
- Q/I profile is essentially **consistent with the model prediction**.
- This Hanle effect is the only way to consistently measure the magnetic fields everywhere in the chromosphere.





Belluzzi et al. 2012

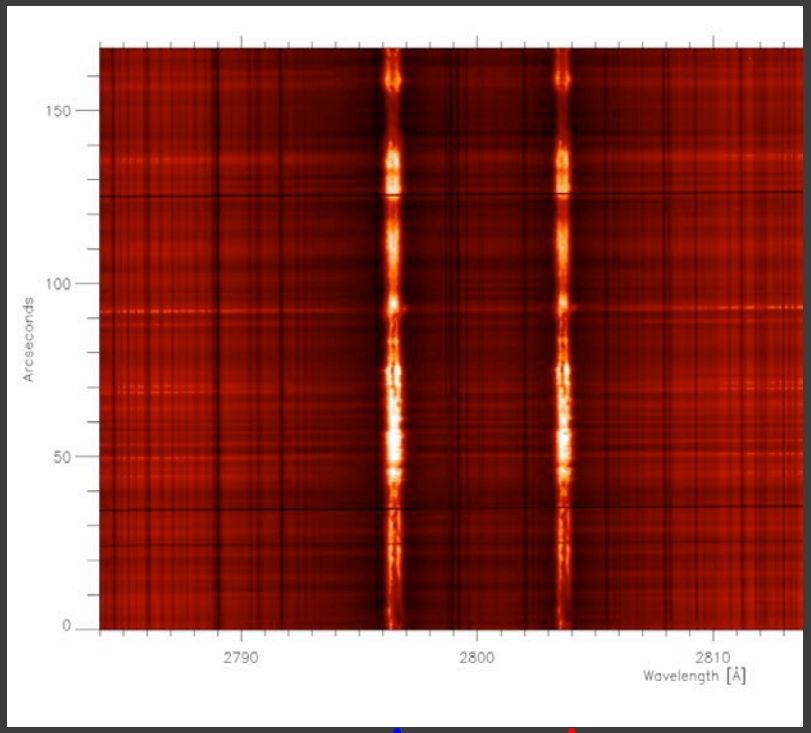
CLASP
Chromospheric Lyman-Alpha SpectroPolarimeter

2

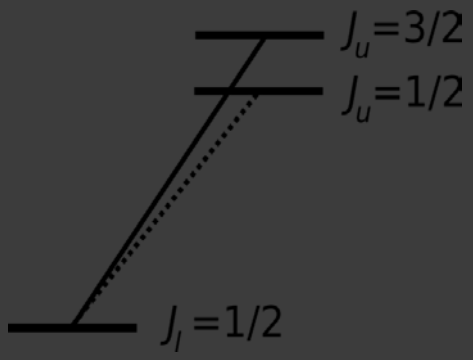
Proposed to fly in Spring 2019.

CLASP 2 to change the wavelength to Mg II h&k, another set of magnetically sensitive spectral lines in the UV at ~ 280 nm.

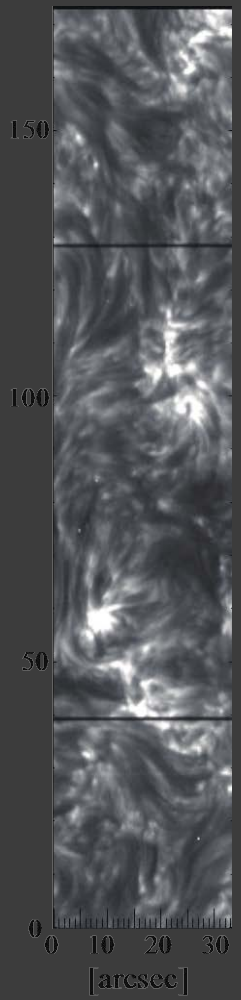
Need to explore multiple lines to determine which is best for routine measurements….



k h

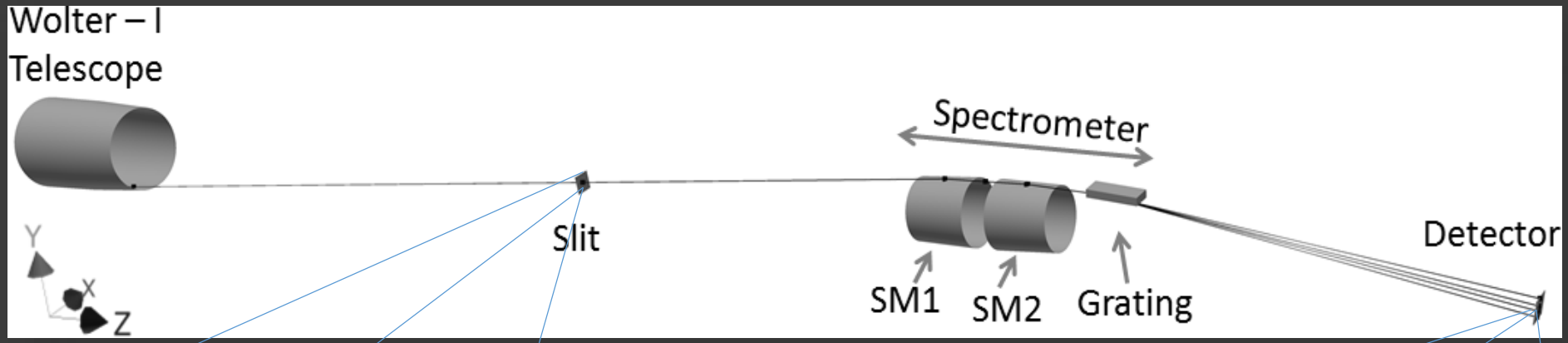


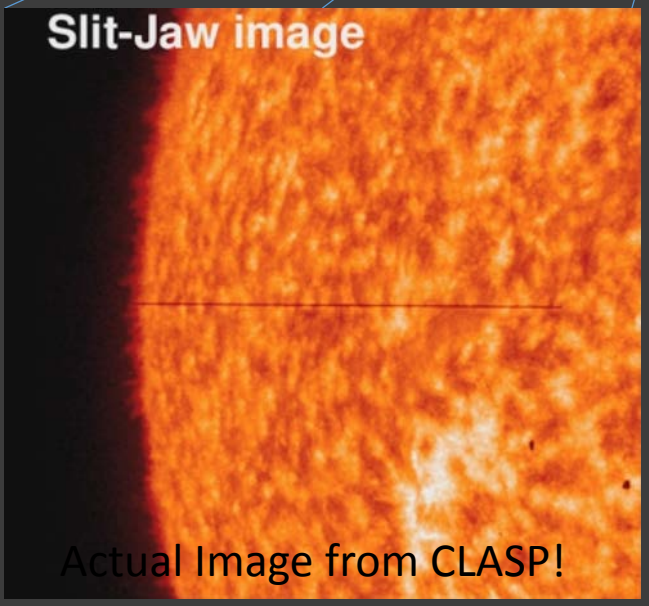
Observing target: QS and plage (if available)

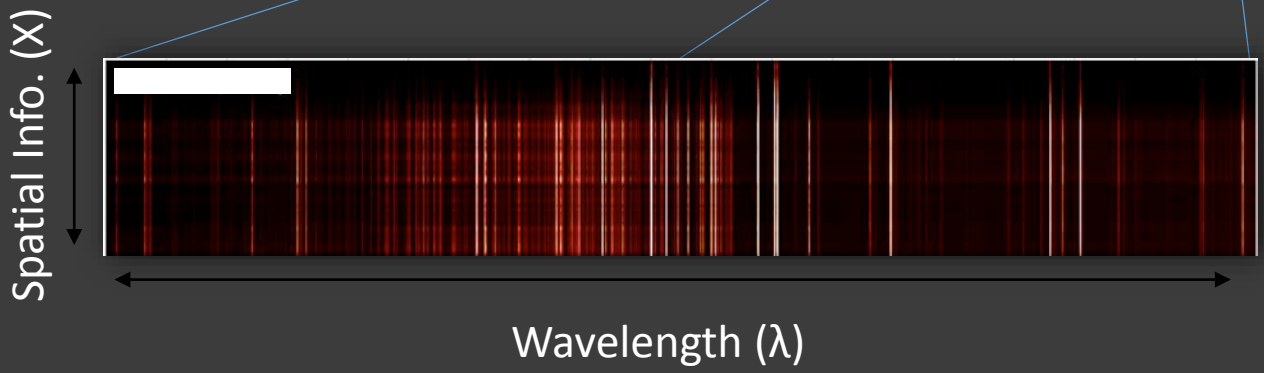


Mg II h& k line core image obtained by IRIS

MaGIXS

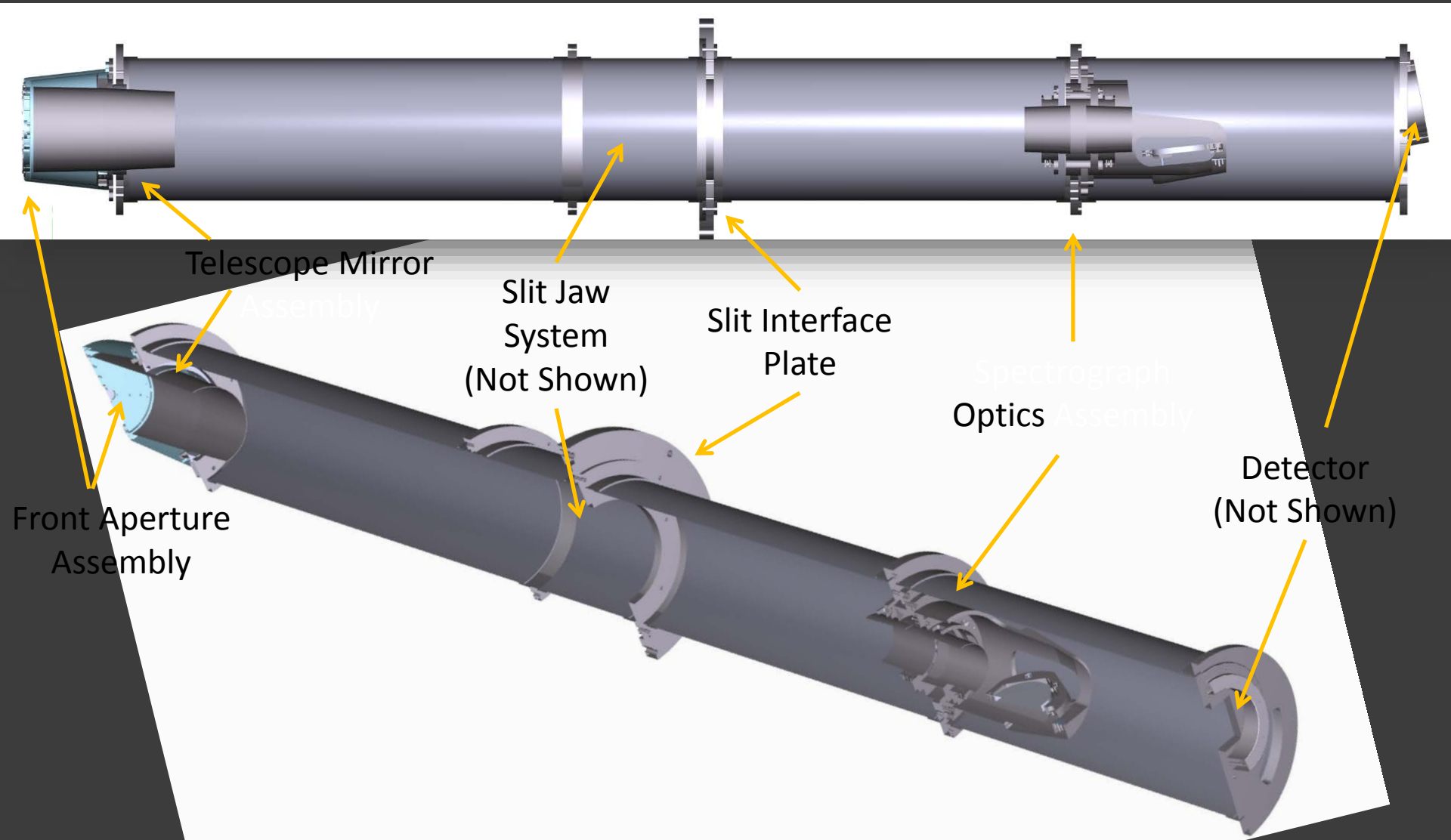




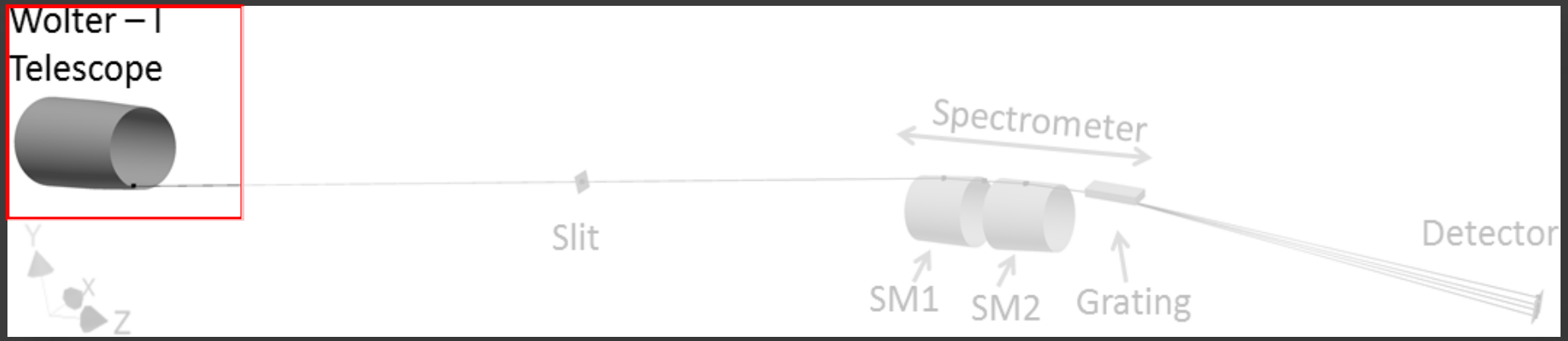


This is what MaGIXS will "see!"

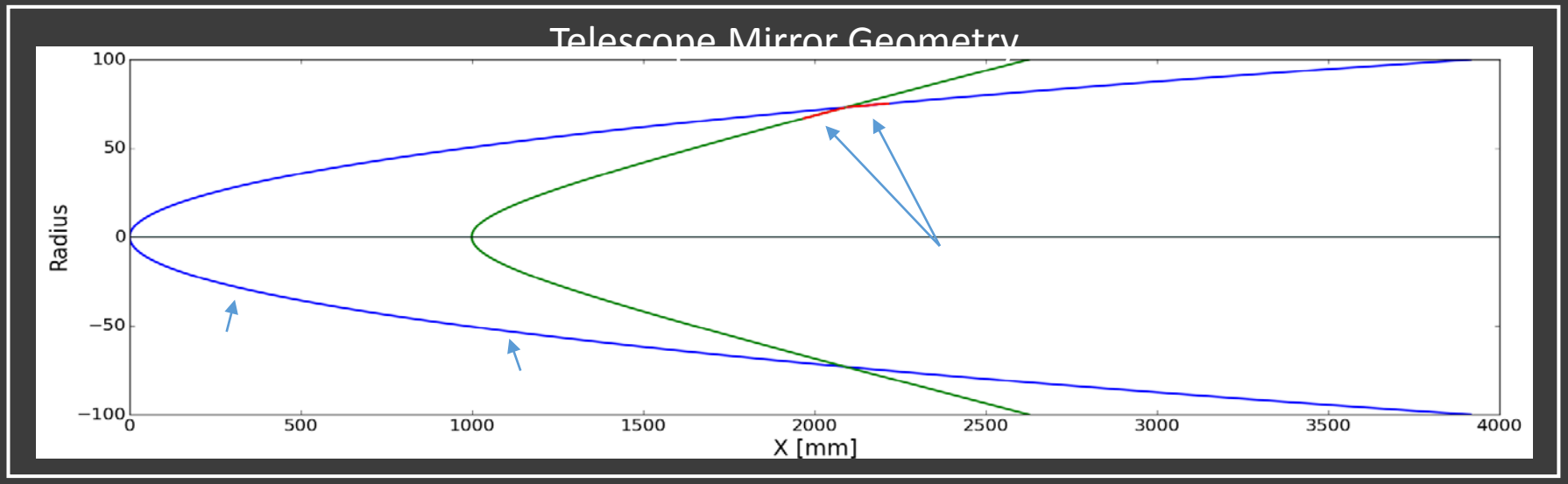
Payload concept



Optical layout



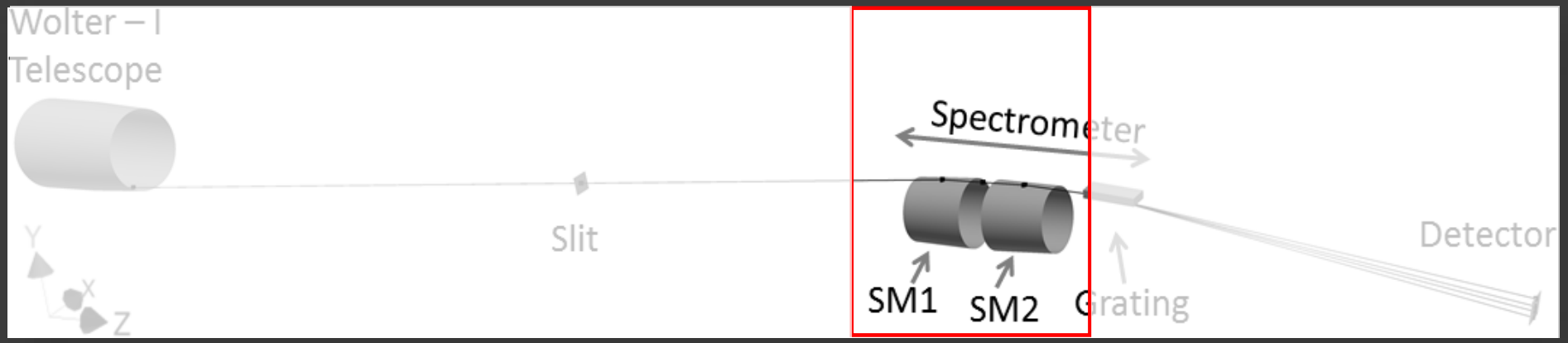
- The **Wolter-I telescope** consists of a paraboloid – hyperboloid combination
  - EFL = 1090 mm, A_G= 960 mm^2, Seg. Len. = 125 mm



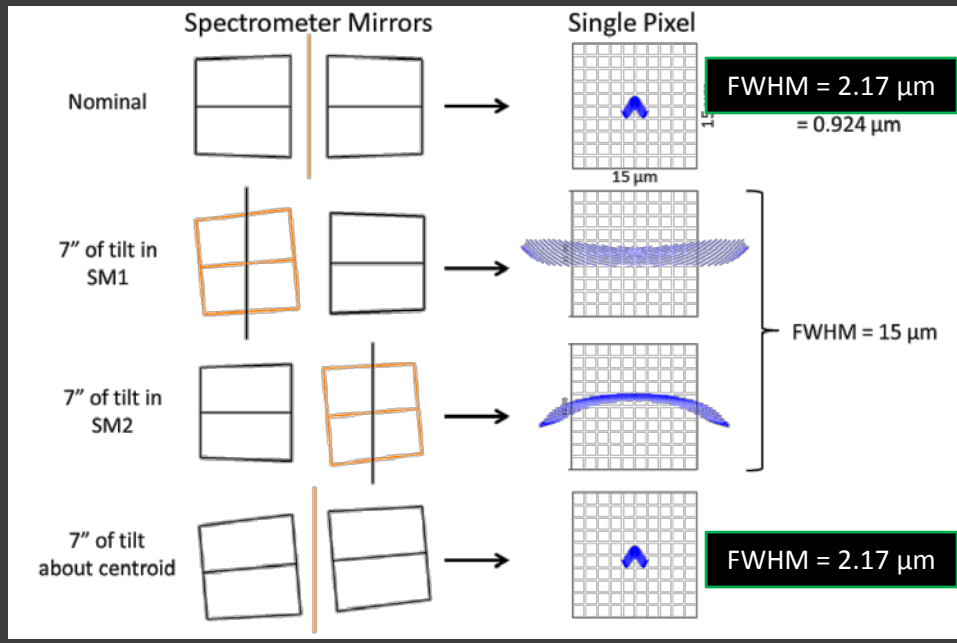
Actual telescope mirror (engineering unit)



Optical layout



- The **spectrometer mirrors** are a finite conjugate paraboloid pair
  - **SM1** focus is coincident with the slit, which collimates the beam
  - **SM2** reimages that collimated beam
  - This configuration reduces off-axis aberration, specifically astigmatism, giving way to maintaining good resolution off-axis
  - These mirror are highly sensitive to alignment error
- EFL = 652 mm, A_G= 685 mm^2, Seg. Len. = 80 mm

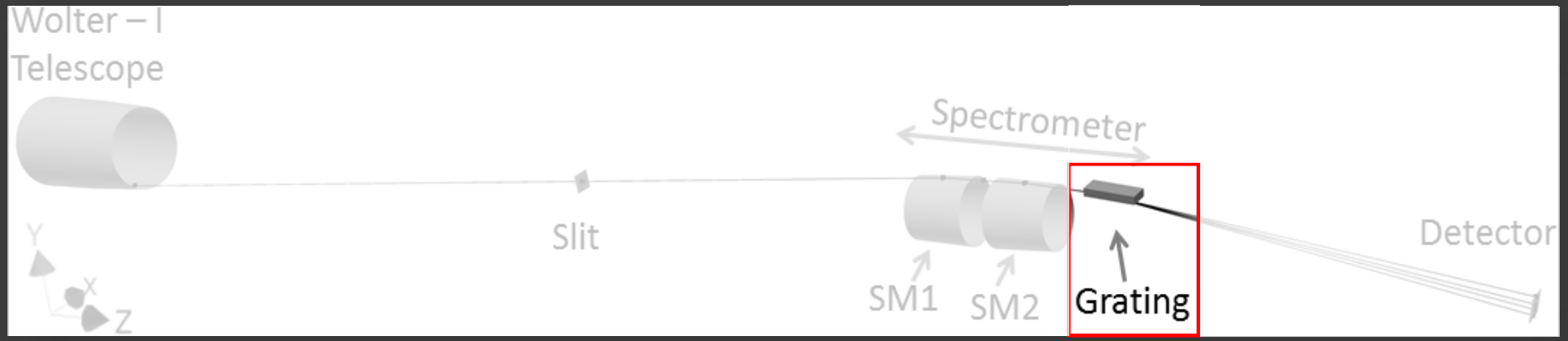


Actual spectrograph mirror

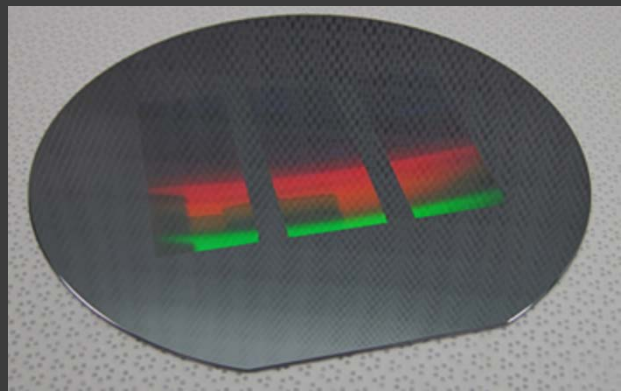




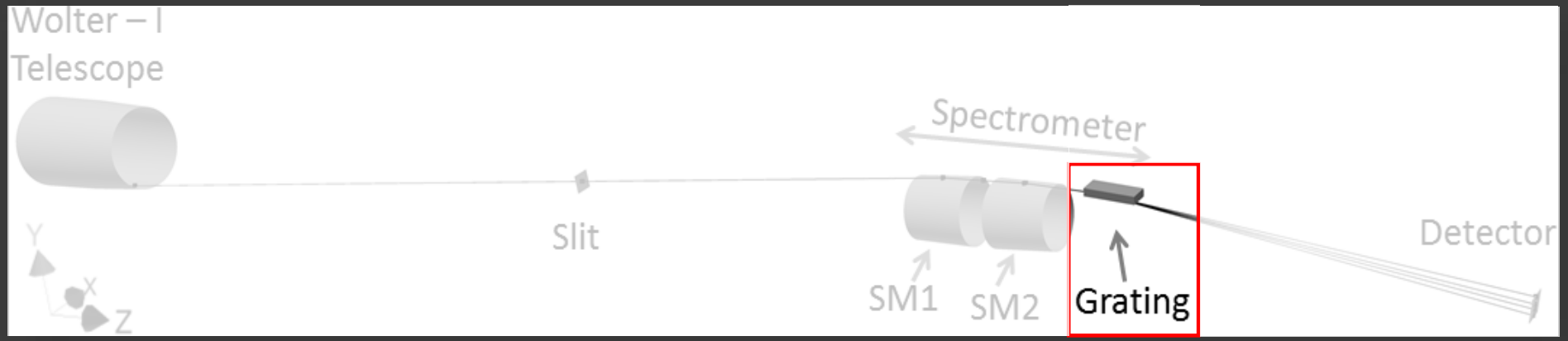
Optical layout



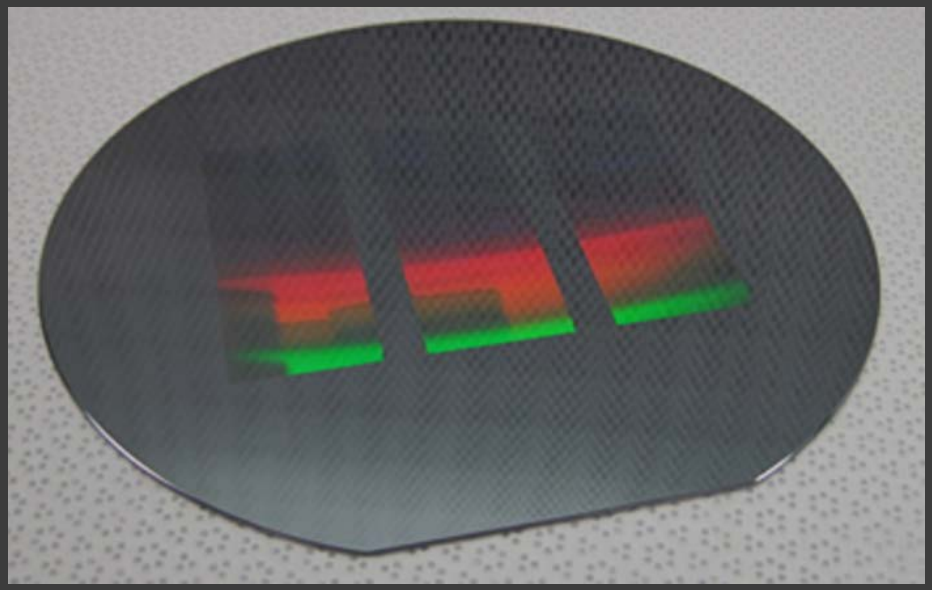
- The **grating** is a varied line space, blazed grating
  - The highly chirped line frequencies direct dispersed wavelengths over varying incident angles to fall at a common location on the detector
  - The chirped line frequencies act as a lens, so alignment is critical
  - The line pattern is directly written on a silicon substrate using e-beam lithography



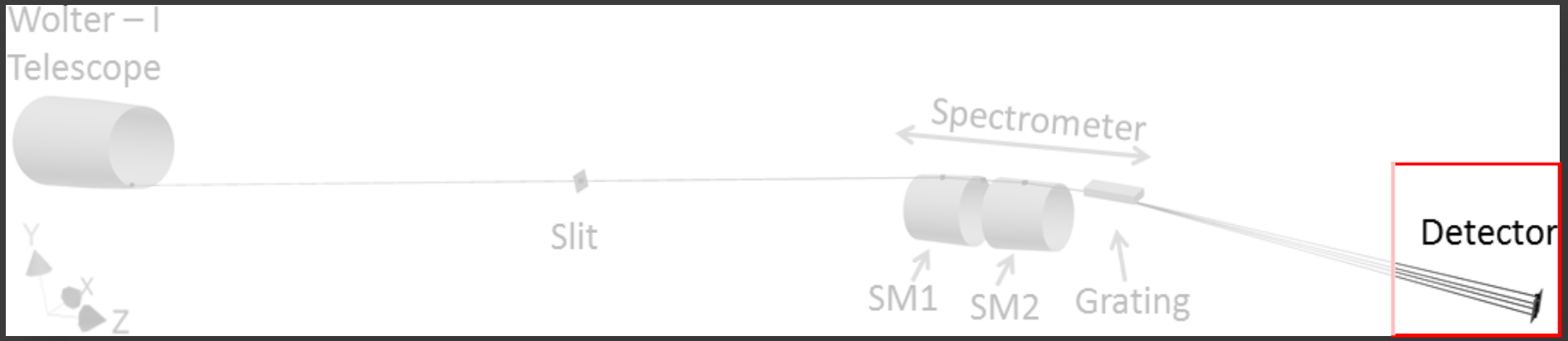
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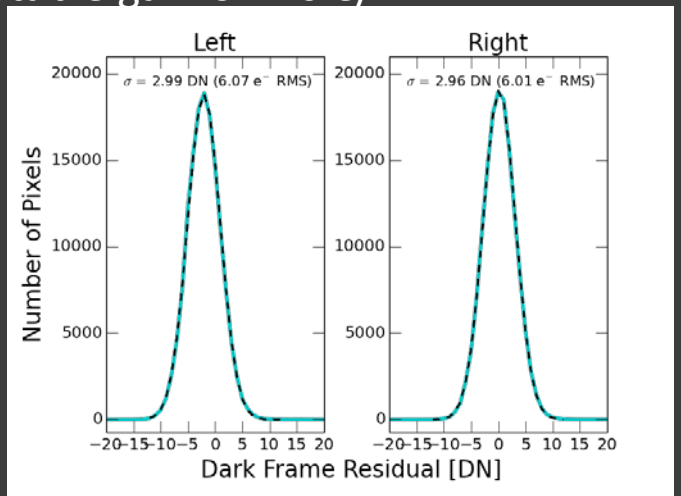
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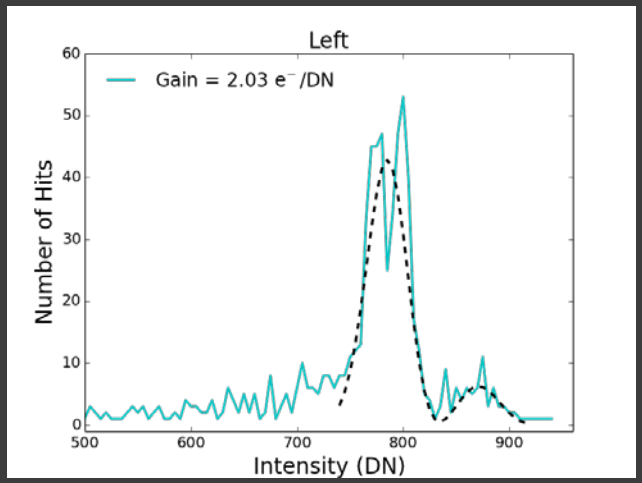


Optical layout



- The **detector** is developed at MSFC and has flight heritage from CLASP and Hi-C II
  - Frame transfer CCD, which enables high-cadence observations
  - Very low dark current (thermal noise)
  - ~ 5 electrons read noise
  - Stable gain of 2.0 e/DN





Thank you!